Towards Nano-scales in Photonics

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We will discuss possible solutions to several key fundamental problems in nanophotonics. The goal of nanophotonics is to explore and manipulate photons at scales (in space, time and energy) that are orders of magnitude smaller than anything previously possible. To accomplish this, one needs to constrain visible or near-infrared photons (the preferred mode of operation: $\lambda \sim 1\,\mu$m) into scales compatible with nanotechnology: 10–100 nm. One also needs to drastically reduce the operational power of optical devices, eventually even down to single photon operating energies.

Most of these problems could be tackled by Surface Plasmon (SP) based devices. SPs enable constraining, and manipulation of light at scales compatible with nanophotonics. Unfortunately, SP-supported designs suffer from two other major disadvantages: huge losses (characteristic of plasmonic materials), and small bandwidth (since SPs are resonance-supported phenomena). We will present a novel class of surface plasmon (SP) assisted components that can overcome all of these difficulties. We will show results of a detailed theoretical and numerical study of the underlying physical mechanism driving these novel SP components.

For a long time, there was a widespread belief in the optics community that alloptical signal processing is not feasible because of the weakness of ultra-fast non-linear effects. There are two most commonly used approaches to enhance non-linear effects. One is to use a material that has as large a non-linear response as possible. The other approach involves finding a structure whose geometrical properties optimize non-linear response. As far as materials go, Electro-Magnetically Induced Transparency (EIT) materials have by far the strongest non-linear response in nature: Kerr non-linearities 12 orders of magnitude larger than in GaAs have been measured in EIT systems recently, thus making EIT-materials the most non-linear materials in nature. Concerning the structural enhancement of non-linearities, Photonic Crystal (PhC) micro-cavities are superior to all other proposed systems: one can design tiny ($O(\lambda^3)$), low operational power (e.g., few tens of mW), ultra-fast (bit rate $>=$ 40 Gbit/sec) devices suitable for any kind of all-optical signal processing, that can be implemented in common optical materials (AlGaAs, $As_2Se_3\ldots$). We will present a detailed theoretical and numerical investigation of the possibility of combining the unparalleled non-linear properties of EIT materials, with superb opportunities of PhC micro-cavities for structural enhancement of non-linear effects in order to produce an all-optical non-linear device that can be operated at extraordinarily low (even single photon) energy levels.